A New Heat-Developable Motion-Picture Print Film

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A dry photographic system applicable to the motion-picture, television and educational film industries. Metro-Kalvar, is described. The system is based upon the phenomenon of light scattering accomplished within a film of thermoplastic resin coated upon a base of transparent polyester. This basic system of photography utilizes ultraviolet exposure and heat development. Details about its departure from traditional motion-picture print materials and procedures are outlined. Developmental tests and equipment are discussed.

The Basic Kalvar Process

The Kalvar Photographic Process is based upon the phenomenon of light scattering, rather than upon that of light absorption as in conventional silver halide materials. The two cases are compared in Fig. 1, where the incident light is absorbed by the silver grains within the developed silver halide film and the incident light is reflected and refracted by the scattering centers within the developed Kalvar film. The film consists of a thermoplastic resin, coated upon a base of transparent polyester. Within the thermoplastic resin, which is normally coated to a thickness of slightly less than 0.0005 in., an ultraviolet-sensitive compound is uniformly dispersed. These molecules of sensitizer are shown as black dots in Fig. 2. Upon exposure to ultraviolet radiation, this photosensitive diazonium salt is decomposed, releasing nitrogen and other volatile products. The internal pressures created by these decomposition products within the thermoplastic vehicle constitute a "latent image" of internal stresses. Upon application of heat, the resin crystallites soften and the gaseous decomposition products expand. A reorientation and ordered recrystallization of the polymer into microscopic vesicles takes place. These vesicles, since they are of a different index of refraction than the surrounding medium, scatter light incident upon them and thus constitute the image. The light-scattering vesicles vary in size from less than 0.5 micron to 2 microns in diameter. Unlike the bubbles that might be formed in gelatin by a similar method, they consist of cavities enclosed by a shell of more highly ordered crystallites than the surrounding medium. As a result, the vesicles are highly resistant to environmental changes and mechanical stresses and provide an extremely stable image.

Sensitivity and Exposure

Kalvar film is not a camera stock. It is a comparatively low-speed material with primary photosensitivity in the near ultraviolet, peaking at 3,850 A. The amount of radiation required to produce maximum density at this wavelength is about 200 milliwatt-sec/sq. cm. The spectral response curve in Fig. 3 shows that the photosensitivity is not limited to a narrow peak but extends from below 3,500 to above 4,300 A. The film is not photographically sensitive to ordinary levels of visible light for short periods of time. Exposure times are determined only by the amount of time required to absorb the 200 milliwatt-sec/sq cm of actinic radiation. Times of less than 1/100 sec have provided adequate exposure. One user of substantial amounts of heat-developable microfilm working with a variable aperture, continuous contact printer-processor is currently operating at a speed of 170 ft/min.

Medium- to high-pressure mercury-vapor lamps which have a high intrinsic brightness, coupled with a desirable spectral output, have proved to be efficient light sources. A high-pressure air-cooled mercury-vapor lamp rated at approximately 1,000 w is currently employed on one of the developmental motion-picture printer-processors.

Latent-Image Stability

The temperature of the film during exposure should not exceed 110 F. Temperatures above this will result in a higher diffusion rate of the latent-image-forming gas, with subsequent reduction of the maximum density obtained.

Since the latent image is comprised of a given amount of gaseous nitrogen, it has a definite decay time dependent on the permeability of the emulsion's thermoplastic vehicle to nitrogen. The decay time can be adjusted by adding modifiers to the basic vehicle resin to increase or decrease its permeability. A current heat-developable microfilm has a latent-image diffusion time of less than 30 sec and is finding useful application as a reversal processed material. Metro-Kalvar motion-picture emulsions require approximately 8 hr for the latent-image gas to escape completely. Experiments show that the film should be developed within 3 min after exposure.

Since one of the film's major features is its simplicity of development by heat alone, this short latent-image life is no problem. All equipment provides for continuous development immediately following exposure and as an integral part of the machine. The inherent latent-image decay precludes the design of printing equipment employing the "down one side — back the other" configuration as

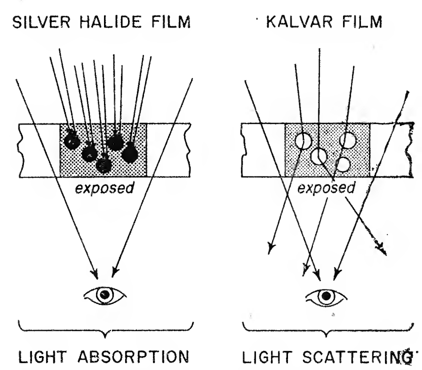

Fig. 1. Comparison of the two systems of photography.

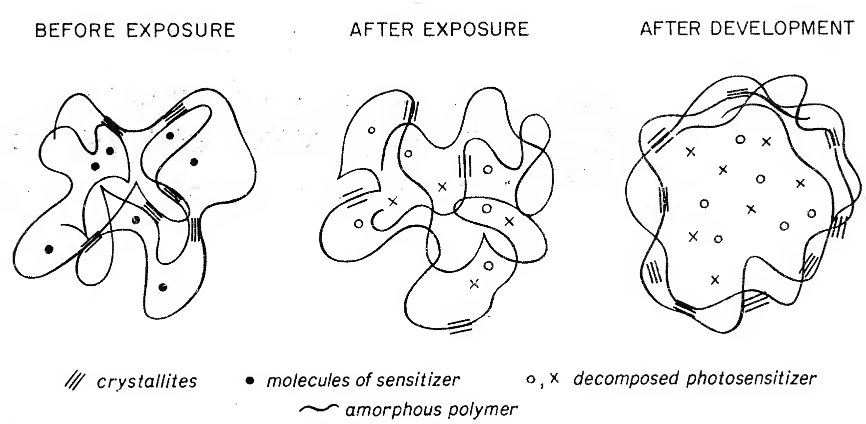

Fig. 2. Schematic of Kalvar Film's process.

Presented on October 15, 1963, at the Society's Technical Conference in Boston, by Noel R. Bacon (who read the paper) and Robert B. Lindemeyer, Metro-Kalvar, Inc., 550 Fifth Ave., New York, N.Y. 10036.

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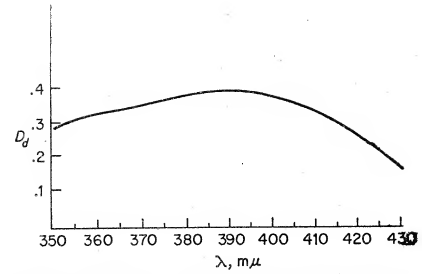

Fig. 3. Spectral response of Kalvar film.

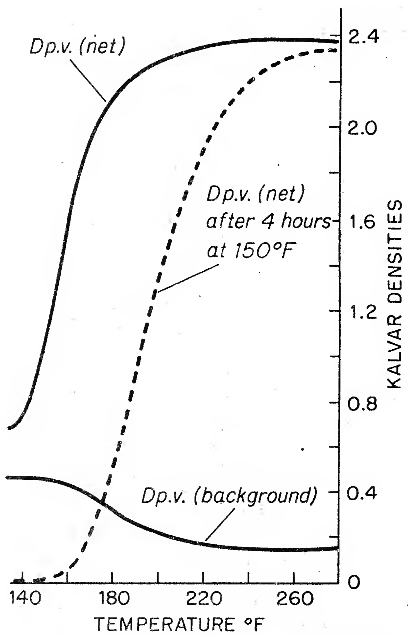

Fig. 4. Kalvar film densities with constant exposure and development time, varying development temperature. D.p.v. = density projection visual.

currently used in several 35/32mm high-speed motion-picture printer applications.

Development and Image Stability

Kalvar film is developed by heat. Any method of heating the film sufficiently will produce the image. A wide variety of techniques have been employed, including heated rollers, heated platens and even forced hot air. The calculated energy requirement to develop the image is approximately 0.635 watt-sec/sq cm/mil thickness of the film.

The gray scale of the light-absorption (silver) type of photographic image is a function of both exposure and development; the gray scale of the light-scattering type of image is primarily a function of exposure. To ensure optimum image characteristics and stability, development must be held within relatively narrow limits. Development times are closely related to development temperatures because total development occurs at a fixed heat level whether that level is reached in seconds or milliseconds. Experimentation has shown a requirement for the emulsion to come to a temperature of 240 F. This temperature was arrived at by comparing the three curves shown in Fig. 4. It can be seen that as the development temperature increases, the background density of the image decreases until approximately 220 F is reached. The upper curve, showing net visual projection density, increases rapidly to approximately 180 F, after which only limited increase is noted from higher development temperature. The dotted line, reflecting the relationship of development temperature to thermal stability of the image, is somewhat more critical. This curve shows the loss in net visual projection density after the developed film has been subjected to 150 F for 4 hr. Design and selection of development heat sources for the desired high-speed operation of the motion-picture printer-processors has required careful consideration of heat transfer characteristics and machine speed vs. dwell-time variables.

Current practice employs a revolving Teflon-coated aluminum drum with heat provided by a 500-w electric blanket laminated to the inside perimeter of the drum. A precision thermostat controls temperature to ±2 F of the desired setting.

Fixing and Image Stability

As with most photographic processes, a fixing technique for the heat-developed film provides for image permanence. After exposure and development the nonlight-struck areas of the film still contain undecomposed sensitizer. The fixing technique consists of exposing the film overall to ultraviolet light. Applying about four times the amount required for maximum exposure completely decomposes the residual sensitizer. The film must then be protected from temperatures in excess of 150 F for a few hours to permit the gas to diffuse completely from the film. The properly exposed, developed and fixed image is one of the most stable of all photographic images. The thermal stability of the image is closely related to the development temperature, as discussed earlier in this report.

Medium- and high-pressure mercury-vapor lamps, which have proved successful for initial exposure, function equally well for the overall fixing exposure.

Sensitometric Characteristics of Light-Scattering Films

As a consequence of the unique characteristics of these light-scattering films, the sensitometric units and standards currently used in silver halide photography do not apply directly to this type of photography. For example, the meter-candle-second exposure units used to express ASA speeds of silver materials are founded on the relative visibility curve of the human eye and obviously cannot be used for heat-developable films, which are sensitive to wavelengths outside the visible spectrum.

Similarly, the familiar sensitometric terms, such as density and contrast, must be redefined when applied to the properties of light-scattering materials. The degree of opacity of the exposed and developed Kalvar image can be measured in terms of diffuse transmission density as outlined in ASA PH2.19-1959. However, when light is incident on the exposed and developed film sample, part of the light is absorbed, part is reflected and part is transmitted; the transmitted and reflected light is highly scattered. The visual diffuse transmission densities of the film are quite low. In fact, the characteristic curve of a typical Kalvar motion-picture emulsion based on visual diffuse densities has an average gamma of 0.35 and a density range of about 0.60. To those unfamiliar with the light-scattering type of photographic image this immediately indicates an extremely low contrast material with limited density range.

For a photographic medium depending on light absorption, the diffuse density is close to the specular or projection density. This is not true for a light-scattering system as may be seen in the generalized schematic, Fig. 5. In any practical use, a photographic material is viewed or projected through an aperture of finite dimensions, here labeled *A*. In the light-scattering system a substantial portion of the transmitted light is scattered outside the angle over which light is collected by the effective aperture. At the same time, the effective density of the heat-developed film strongly depends upon the cone angle subtended by the light-gathering element, whether it be the eye, a projector lens or the photosensitive receptor of a densitometer. This is shown in Fig. 6 where the effective or projection density for various apertures is plotted against the logarithm of the exposure.

These characteristics have been taken into consideration in the design and development of new measuring techniques for the photometric evaluation and process control of Kalvar photography. The primary objectives in the development of these new techniques have been to provide measurements that will readily correlate with the traditions and experience of the photographic industry and that will accurately represent the product's capabilities in ultimate projection viewing.

This departure of ultimate use conditions from the conditions during diffuse density measurement is of concern in all types of photography. The American Standards Association Committee on Sensitometry is currently giving careful consideration to this problem. A recently created ASA Subcommittee, PH2-28, has been charged with the responsibility of revising the Diffuse Transmission Density Standard to include other types of density such as projection density. The

Kalvar Corporation is playing an active role on that subcommittee.

Practical Sensitometry and Control Techniques

Current techniques employed to provide sensitometric evaluation of various Kalvar emulsions and process control represent only a slight modification of procedures widely used in the photographic industry.

A sensitometer is used to expose strips for basic emulsion characteristic evaluation. This unit employs an ultraviolet light source carefully positioned in relation to a curved aperture containing a calibrated density modulated wedge.

Exposures are developed on a small laboratory hot-roller capable of maintaining set development temperatures to ±2 F.

Sensitometric strips are read on either a standard motion-picture densitometer providing visual diffuse transmission densities or a projection reading densitometer with modified aperture providing readings directly relatable to ultimate projection conditions. These readings are plotted in a standard H&D characteristic curve for routine evaluation of speed, gamma, density and exposure scales. These same readout and evaluation techniques are employed for process control where the sensitometric strips are exposed and developed on the Metro-Kalvar Motion Picture Printer-Processor under varying conditions of machine speed and light intensity.

Research and Development

The technology of silver halide photography has been evolving for over a hundred years. The light-scattering principle of image formation has been known for nearly the same length of time; but it is polymer chemistry that has provided the means to create light-scattering images in a practical way. Metro-Kalvar was formed by Metro-Goldwyn-Mayer and the Kalvar Corporation to adapt the Kalvar Process to the motion-picture, television and educational film industries.

Progress toward that goal has included basic research and formulation of appropriate film emulsions at the Kalvar Corporation in New Orleans and design, fabrication and testing of bread-board printing and processing equipment at the M.G.M. Laboratories in Culver City. The manufacture of a pre-production prototype 16mm printer-processor has begun at Calvin Productions in Kansas City. The specifications for this machine include a desk top model, an operating speed of 70 ft/min, separate sound and picture printing heads and 1,200-ft film capacities.

Research has been conducted on the problems of splicing the polyester-based films. The cements employed with conventional film splicing are ineffective with polyesters; however, tape splicing has been used with excellent results. High-strength values are retained, since the tape employed is also polyester.

Conclusion

In conclusion, it is appropriate to set forth the major advantages of the Metro-Kalvar System:

(1) With maximum sensitivity in the near ultraviolet region, the need for a darkroom is eliminated.

(2) It is a dry process, requiring no chemicals for processing, because heat alone develops the image.

(3) The basic formulation of materials provides for prolonged shelf life and convenient storage conditions.

(4) The unique structure and distribution of the light-scattering image affords high resolution, excellent image stability and grain-free projection characteristics.

(5) The combination of a predominantly thermoplastic emulsion and a tough polyester base provides for a scratch-resistant, long-wearing film.

(6) The standard 3-mil thickness of the high-strength polyester base allows 1,000 ft of film to be wound on a standard 600-ft reel.

(7) The combined process of exposure and development provides immediate access to results.

Discussion

*George Lewin** (*Army Pictorial Center*): Is it possible to put this Kalvar emulsion on conventional cellulose acetate base?

Mr. Bacon: It is.

Mr. Lewin: Do you arrive at the optimum exposure for your soundtrack by cross-modulation or inter-modulation tests?

Walter G. Eggers (*M.G.M. Laboratories, Inc.*): Conventional cross-modulation tests have not proven, at this moment, of any value as far as Kalvar film is concerned. The densitometry of Kalvar is a new field, and the numbers we derive from a densitometer that has been developed for Kalvar film are not meaningful in the same sense that silver halide densities are. When we try to draw a cancellation curve we are, in some cases, comparing apples against oranges, because the

* Deceased November 1963.

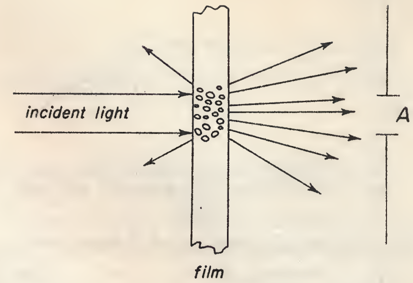

Fig. 5. Schematic of function of Kalvar density.

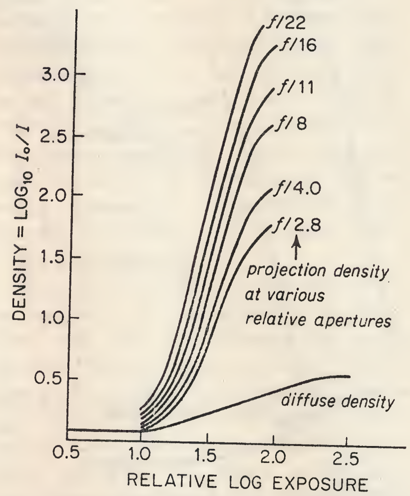

Fig. 6. Projection density as a function of aperture.

two densities; that is, the density of the silver optical transfer and the Kalvar print have to be measured by different parameters. We have, however, investigated this by means of listening tests. I might ask you a question: What did you think of the sound on this particular print?

Mr. Lewin: Well, I felt that the sound was quite adequate. Was it area or density track?

Mr. Eggers: That's variable area.

Mr. Lewin: And is it reproduced with a conventional photoelectric cell?

Mr. Eggers: The conventional cell.

Mr. Lewin: Have you been successful with the variable-density track as well as area.

Dr. Robert T. Nieset (*Metro-Kalvar*): No work has been done on variable-density pursuits. You can see that, with the limited maximum density that we had, the dynamic range on variable-density recording with Kalvar would be pretty small at the present time. I'd like to add one other comment: since the soundhead always looks at the soundtrack with a much smaller physical aperture than does a projector lens, the control of exposure with relationship to sound and picture is not as critical as it would be in the silver case. The density of the soundtrack, because it's being used with such a small aperture, is always much higher than the density of the projected image.